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VISUALIZATION OF BATTLEFIELD OBSCURANTS

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ABSTRACT

The EOSAEL Combined Obscuration Model for Battlefield Contaminants (COMBIC) module models the transmittance of seven electro-optical wavelengths through 30 obscurant sources types. Designed as a war gaming tool, COMBIC computes the transmissivity along selected lines of sight, but does not allow realistic visualization of the obscurants. Because of their amorphous nature, obscurant clouds are particularly difficult to model with traditional computer graphics techniques, which employ flat polygons to model clearly defined features. Grumman Data Systems has developed non-traditional computer graphics techniques using fractal ellipsoids to model clouds realistically but economically. This paper describes work initiated by the U.S. Army Topographic Engineering Center to integrate Grumman graphics technology with COMBIC to provide realistic visualization of battlefield obscurants. COMBIC Phase I subroutines are used to generate an obscurant cloud envelope. This envelope is then filled with fractal ellipsoids which can be manipulated dynamically to generate animated sequences of the obscurant's development.

1. INTRODUCTION

Obscurants are such an important factor in the battlefield that smoke obscurants are generated deliberately to screen offensive operations. To provide computer models describing the physics of battlefield obscurants, the U.S. Army Atmospheric Sciences Laboratory has developed the Electro-Optical Systems Atmospheric Effects Library (EOSAEL) (Shirkey et al, 1987). The EOSAEL module, Combined Obscuration Model for Battlefield Contaminants (COMBIC) (Hoock et al, 1987) models a wide range of battlefield obscurants, predicting time histories of obscurant envelopes and transmittance from given meteorological and surface conditions. With this capability, COMBIC provides a firm basis for visualizing the effects of battlefield obscurants but does not include the graphic capability to do so. In particular, COMBIC generates smooth plumes which lack the statistical variations of real plumes. These variations are needed to simulate holes and thin regions in the plumes which are important to tactical operations as windows of opportunity.

Currently, computer simulation of battlefield scenes is limited to the representation of hard, clearly defined surfaces such as terrain and targets. Little has been accomplished in modeling obscurants because their amorphous nature does not lend itself to traditional computer graphics techniques which use flat polygons bounded by straight edges to model scene features. The U.S. Army Topographic Engineering Center's (TEC) Terrain Visualization system uses such techniques to model terrain and targets, but does not include capability to model obscurants,

Grumman Data Systems has taken a nontraditional approach using fractal ellipsoids to model cloud volumes economically (Gardner, 1985). A fractal ellipsoid is a geometric ellipsoid that has been processed by applying a 3-D fractal texture to simulate natural variations in mass distribution. By modulating the translucence and surface shading of the ellipsoid, the fractal texture simulates statistical variations in transmittance and reflectance characteristic of variations in mass.

The Topographic Engineering Center recommended integrating Grumman graphics with EOSAEL to support TEC's Terrain Visualization effort. This study was undertaken to realize this goal by applying Grumman graphics technology to COMBIC obscurant models (Gardner, 1991).

2. GRAPHICS DEVELOPMENT

2.1 INTRODUCTION

This section describes the development of graphics techniques to provide realistic visualization of COMBIC obscurants by using Grumman's fractal ellipsoids to fill the obscurant envelopes generated by COMBIC.

2.2 DESCRIPTION OF COMBIC

COMBIC was designed as a war gaming tool to predict transmittance through an obscurant as a function of sensor wavelength and optical thickness along a specified line of sight. COMBIC computes transmittance, Tr, from these factors by the following equation.

$$Tr = e^{-\alpha(\lambda) CL} \tag{1}$$

where α is the extinction coefficient dependent on the wavelength, λ, of the sensor, and CL represents the integral of the obscurant mass over the path length.

COMBIC includes geometric models for obscurant clouds which enable the computation of the *CL* term. COMBIC uses a coordinate system relative to the wind with the origin at the obscurant source, and *X*, *Y*, and *Z* representing the downwind, crosswind, and vertical directions.

COMBIC models obscurant clouds with one to five subclouds. Each subcloud is defined either by a Gaussian puff or by a continuous Gaussian plume. A Gaussian puff is modeled by an ellipsoid whose mass has a Gaussian distribution and is used to represent an instantaneous subcloud, for example, a puff of dust or a fireball from a munition detonation. Figure 1 shows the geometry of a typical Gaussian puff.

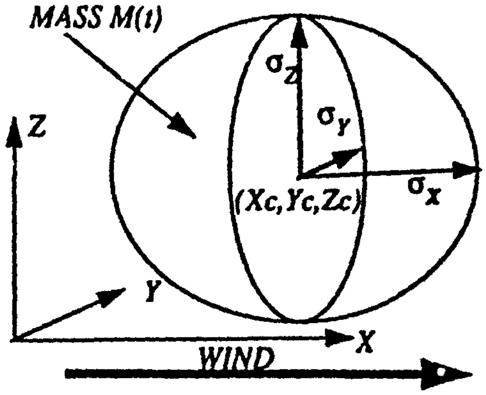

Figure 1. Gaussian puff geometry

COMBIC defines the Gaussian variation on mass concentration as

$$C(X,Y,Z) = \frac{Mass}{(2\pi)^{3/2}\sigma_X\sigma_Y\sigma_Z} e^{-\frac{1}{2}D^2} \tag{2}$$

where:

$$D^2 = \left(\frac{X-X_c}{\sigma_X}\right)^2 + \left(\frac{Y-Y_c}{\sigma_Y}\right)^2 + \left(\frac{Z-Z_c}{\sigma_Z}\right)^2 \tag{3}$$

A Gaussian plume, which looks like a bent cone, is used to represent the elongated envelope of a continuous obscurant such as smoke. Figure 2 shows a typical plume.

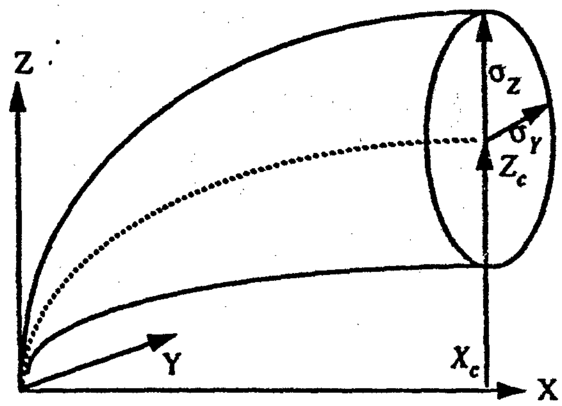

Figure 2. Gaussian plume geometry

COMBIC performs its function in two phases. Phase I uses differential equations driven by meteorological and terrain surface data to compute a time history of the obscurant trajectory. The time history represents a geometric envelope in terms of the downwind coordinate system.

For an instantaneous puff, the time history contains the X and Z positions (Y is always zero) and the X, Y and Z dimensions, computed at specific points in time. The time history for a continuous plume defines the leading (downwind) edge of the obscurant by its X and Z positions and its X, Y and Z dimensions, computed at sampled points in time. For plumes, Phase I also computes a time history of mass production from the continuous obscurant source.

In Phase II, COMBIC uses the trajectory and mass data generated in Phase I to compute transmittance through a given line of sight.

2.3 APPLICATION OF COMBIC

Development of software to allow visualization of COMBIC output was achieved in two steps:

1. The essential features of the COMBIC software for producing trajectory time histories and mass production tables were extracted from the original COMBIC code and compiled into a new program called "COMB_I." Phase II subroutines were not included.

2. Graphics techniques and software were developed to generate and display fractal ellipsoids filling the trajectory envelopes produced by COMB_I. This software comprises a second computer program called "COMBICV," standing for "COMBIC Visualization."

2.4 COMBICV DEVELOPMENT

COMBICV uses the COMBIC model to represent the geometry and transmittance of an obscurant with enough detail to allow realistic visualization. Radiance is approximated by Grumman graphics techniques which use diffuse surface reflection of ellipsoids modulated by a texturing function.

2.4.1 COMBICV Geometry Model

The strategy for developing the geome... model was to apply the Grumman ellipsoid modeling technique in the most straightforward way to fill the obscurant envelope defined by the COMBIC trajectory time history data. The key problem was to provide a realistic yet computationally economical dynamic capability to produce animation of obscurant development.

2.4.1.1 Geometric Model for Instantaneous Puffs

COMBIC models an instantaneous puff as a Gaussian ellipsoid and produces a time history of the position and size of the ellipsoid as it moves downwind. COMBICV fills the Gaussian ellipsoid with subellipsoids defined by parameters specifying the extent of the Gaussian puff, the number of subellipsoids used to fill the puff, and the X, Y and Z dimensions of the subellipsoids.

For each point in time, COMBICV accesses the trajectory data and determines by linear interpolation what the proper puff position and dimensions are. COMBICV scales these dimensions and then positions the preset number of subellipsoids to fill the puff. As the puff moves downwind in time, it expands. Because the number of subellipsoids in each direction is kept constant, their spacing is increased to fill the puff. At the same time, the dimensions of each subellipsoid are increased as a predefined fraction of the puff dimensions. Figure 3 shows the COMBICV geometric model for an instantaneous puff with random variations in subellipsoid size and position added to provide realism.

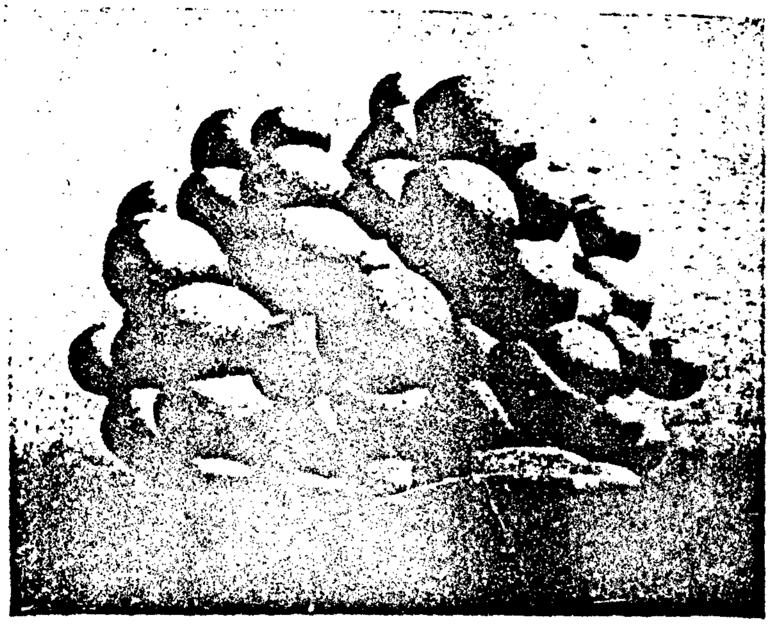

Figure 3. COMBICV geometric model for an instantaneous puff

2.4.1.2 Geometric Model for Continuous Plumes

COMBICV model uses a source footprint of circular shape with a defined radius. Within this footprint at equally spaced intervals, starting points for a specified number of ellipsoid columns are defined. The center column follows the trajectory time history center line, while the other columns fan out to fill the trajectory envelope. This is achieved by using the centerline data along with the trajectory dimension data which expands downwind. Each column is shifted from the centerline by an amount depending on its source position relative to the center of the footprint and the dimensions of the envelope.

The next step in the geometry model is to position ellipsoids along each column. An efficient approach is to space the ellipsoids to minimize overlap while maintaining realistic contiguity. This can be done in the following manner. For any given time, T_{traj}, at which we are viewing the obscurant, we position the ellipsoids starting from the plume downwind leading edge. The first (farthest downwind) ellipsoid is positioned from the trajectory time history data at time $T_1 = T_{traj}$. The downwind and vertical positions, X_{p_1} and Z_{p_1}, are computed from the trajectory data using linear interpolation. The trajectory dimensions, σ_{X_1}, σ_{Y_1}, and σ_{Z_1} at time T_1 are also determined by interpolation. These σs are scaled by a user-specified parameter to define the dimensions, X_{s_1}, Y_{s_1}, and Z_{s_1}, of the most downwind ellipsoid in the column. The values X_{s_1} and Z_{s_1} provide data for determining the next time T_2 at which we will position the second ellipsoid slightly upwind of the first such that its center lies on the first ellipsoid to provide good overlap. Size data is computed at T_2 to determine the third ellipsoid, and the process is continued until the last ellipsoid in the column near the source is produced at time T_n. Figure 4 shows the final column produced in this manner.

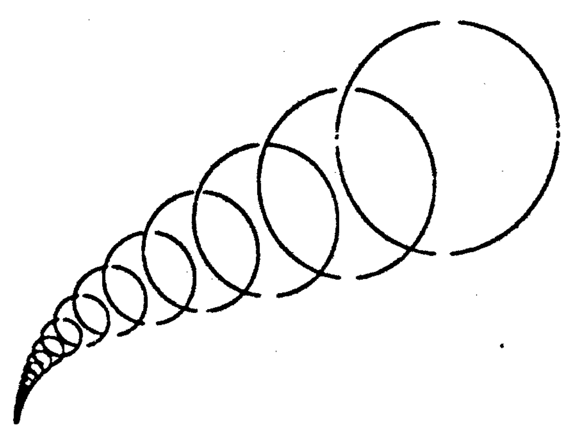

Figure 4. Subellipsoid spacing in a column

Using this approach for multiple columns which fan out fills the envelope well. Random variations in the positions and dimensions of each of the ellipsoids can be applied to add realism as shown in Fig. 5.

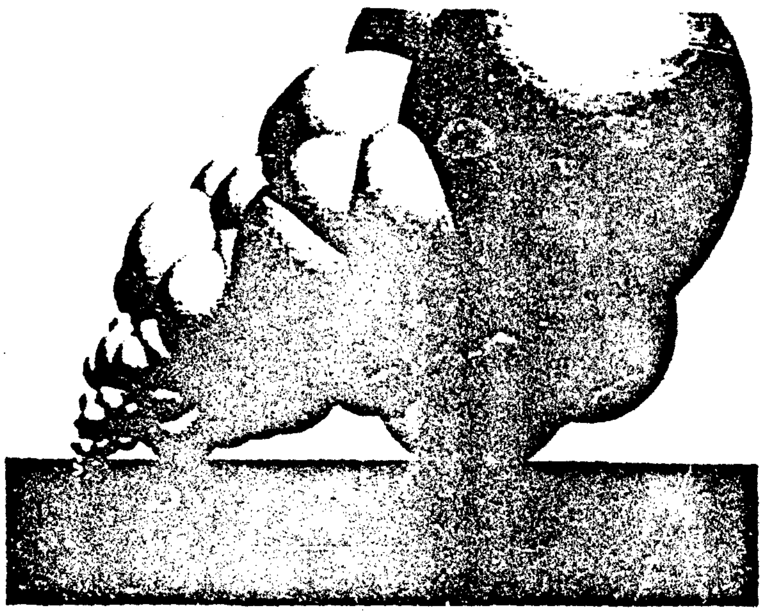

Figure 5. COMBICV geometric model for a continuous plume

2.4.2 COMBICV Transmittance Model

To provide visualization of the COMBIC obscurant model, COMBICV determines the transmittance through an obscurant for the line of sight through each image pixel in two steps. First, the transmittance through each subellipsoid covering the pixel is computed. Then the combined transmittance through all ellipsoids covering the pixel is computed. The first step is further partitioned into three substeps:

1. The transmittance through the center of the subellipsoid is computed.
2. A Gaussian variation in subellipsoid mass concentration is approximated by increasing the transmittance toward the silhouette of the subellipsoid.
3. Statistical variations in mass concentration are simulated by applying a fractal function which modulates transmittance.

2.4.2.1 Center Transmittance of Subellipsoids

The center transmittance for each subellipsoid is based on the mass contained in the subellipsoid. Mass is assigned to each subellipsoid by partitioning the total mass of the obscurant according to the position of the subellipsoid within the obscurant envelope. COMBICV partitions mass differently for puff and plume obscurant models.

For a puff, COMBICV partitions the total puff mass among the subellipsoids by using eq. (2) to compute a weighting factor for each subellipsoid based on the coordinates of the subellipsoid center. The weighting factor is normalized to ensure that the total mass is exactly distributed among all subellipsoids. Mass assignment is independent of trajectory time, T_{traj}, of the puff, except that the total mass is adjusted for evaporation or deposition.

The plume model is treated differently to account for the time distribution of mass resulting from a continuously burning source. In this case, total airborne obscurant mass is partitioned among subellipsoids in each column using the mass production history data. For multiple columns, the mass must also be partitioned across the columns. COMBICV allows a simple averaging based on the number of columns, but also provides the option of weighting the average to approximate a Gaussian distribution across the obscurant envelope, producing a greater concentration of mass for subellipsoids in columns near the plume centerline.

Once the fraction of total mass has been determined for a subellipsoid, the distribution of mass within the subellipsoid is treated as Gaussian and the transmittance through the center is computed using digital integration of eq. (2).

2.4.2.2 Gaussian Variation of Subellipsoid Transmittance

To approximate a Gaussian variation in subellipsoid mass, a Gaussian variation in transmittance is approximated by increasing the transmittance from that at the center of the subellipsoid to a value of unity at the silhouette of the subellipsoid image. This operation is performed during image rendering using a high-order function in image coordinates based on the ellipse which represents the perspective projection of the subellipsoid silhouette.

2.4.2.3 Fractal Variation of Subellipsoid Transmittance

During image rendering, COMBICV also simulates natural variations in subellipsoid mass distribution by modulating transmittance with a three-dimensional texture function based on scene coordinates of the subellipsoid surface. The function is an abbreviated fractal function composed of short summations of cosines in each of the three scene coordinates (Gardner, 1991). At each image point on the subellipsoid, the corresponding scene coordinates of the subellipsoid are calculated and the function computed to modulate the transmittance of the subellipsoid.

2.4.2.4 Combined Transmittance for Multiple Subellipsoids

From eq. (1), for each image pixel, the total transmittance through N ellipsoids covering the pixel can be computed by taking the product of the individual transmittance values.

Figure 6 shows the result of the COMBICV geometric and transmittance models for source 30 modeled with 13 columns emanating from the footprint.

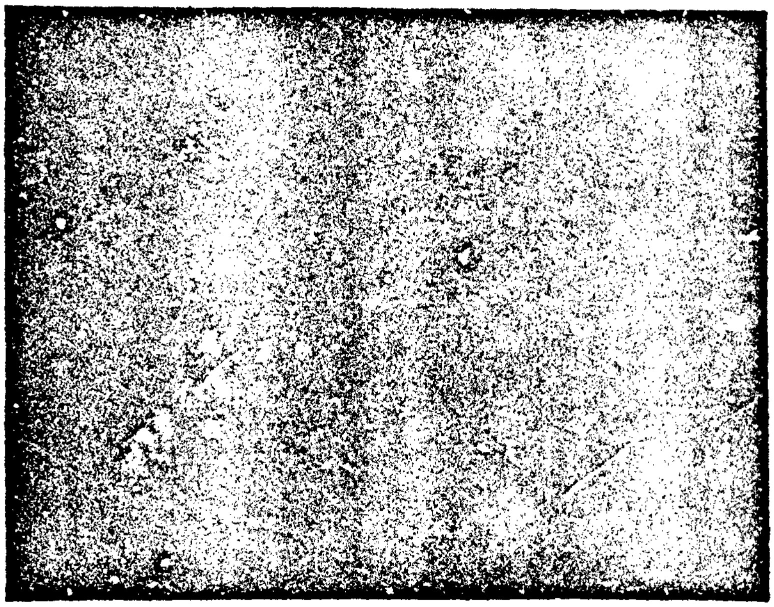

Figure 6. COMBICV model for source 30

Figure 7 shows COMBIC source 25 (fog oil) visualized in a synthetic terrain setting.

Figure 7. COMBIC source 25 (fog oil) in a synthetic terrain scene

3. VERIFICATION OF COMBICV

To provide assurance that COMBICV produces visualization representative of COMBIC, software was written to generate images of the basic COMBIC obscurant envelopes. In addition, tests were performed to provide statistical comparison with real obscurant data. Visual comparisons between COMBICV output and the approximated output of COMBIC looked reasonable, and average transmittance values agreed well for all seven COMBIC wavelengths. The comparison with real data produced similar statistical structures. The imagery generated by COMBICV should therefore provide the Army with a valid tool for visualizing battlefield obscurants with acceptable accuracy and realism.

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Laslo Greczy, of the Topographic Engineering Center, initiated this study by suggesting that Grumman Data Systems computer graphics techniques be applied to EOSAEL models.

The success of this research was greatly enhanced by the cooperation of Dr. Donald Hoock, the principal author of COMBIC. Dr. Hoock gave guidance in the use of COMBIC and suggested many of the approaches taken. He also suggested a means for verification and supplied data for comparing the visualization model with real obscurants. Although the original contract definition called for the modeling of a single source viewed by a single sensor, Dr. Hoock's contribution enabled the modeling of all 30 sources viewed by any of the seven sensors.

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